Linking Weather and Climate

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This presentation provides an overview of major phenomena and mechanisms linking weather and climate variations, with a focus on a subset of major, recurrent phenomena that impact extratropical wintertime weather and climate variations over the Pacific-North American region. While progress in advancing understanding has been impressive, research has also illuminated areas where significant future gains are possible. Emerging thrusts in international and national research priorities suggest that over time artificial distinctions will be removed between "weather" and "climate", as we begin to achieve a more unified understanding of phenomena and processes that bridge time scales. We discuss these research thrusts, which are likely to serve as increasingly vital components of an overall research strategy in earth system science.

Introduction

Historically, the atmospheric sciences have tended to treat problems of “weather” and “climate” separately. The real physical system, however, is a continuum, with fast “weather” processes profoundly influencing climate variations and change, and, conversely, slower “climate” fluctuations and change affecting the weather that we experience. While this past approach has served important purposes, it is becoming increasingly apparent that in order to make progress in addressing many societally important problems, from assessing risks of future hurricane activity to the possibility of abrupt climate change, we require an improved understanding of the connections between weather and climate. As we move toward a more unified view of phenomena and processes across time scales, the problem of understanding the relationships between “fast” and “slow” processes - effectively, the links between weather and climate - is emerging as an important new research priority. This presentation suggests some near-term directions where prospects for advances appear most likely in building our understanding of the relationships between weather and climate.

In approaching this broad problem, it is useful to consider three related sub-questions:

1) How do climate variations and change affect weather phenomena?

2) How do weather phenomena affect climate variations?

3) What are key phenomena and processes that bridge the time scales between synoptic-scale weather (time scales of order a few days) and climate variations of a season or longer?

To give a specific example for the first question, we might ask how do climate variations (or change) influence the probability of occurrence or potential intensity of hurricanes? This is a topic of enormous societal importance, and an active focus for current scientific research. The reciprocal question is: what are the effects of hurricanes on the climate system? Hurricanes clearly impact the atmospheric heat budget through the transfer of heat from the tropical oceans into the tropical upper atmosphere, and potentially also to higher latitudes. More subtly, by altering the upper ocean heat balance hurricanes can change the ocean thermohaline circulation, and thereby induce longer-term climate variations. More generally, many hydrological processes, such as clouds, moist convection, and water vapor transports operate on fast "weather" time scales, and yet also profoundly impact climate variations and change. The third question addresses the "no man's land" that lies between approximately a week and a season. Tropical variations such as the Madden-Julian Oscillation (MJO) and air-sea coupling are examples of

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important phenomena and processes that occur on these scales.

While the presentation touches on the first two questions, the main emphasis is on this third question and, especially, on identifying potential directions for near-term progress. In addressing this question, it is important to recognize that the problems can – and should – be attacked from multiple directions, "from the weather side out" (from days to a few weeks out), "from the climate side in" (how seasonal and longer fluctuations affect weather variability), as well as through analyses of phenomena and processes that bridge time scales.

<u>High priority Issues</u>

Issue 1: Organization of tropical convection

This is the **mega-issue.** It cuts across time scales from short and medium-range weather forecasts to understanding and projecting regional climate variations and change. Studies suggest that beyond 7-10 days, variations in tropical heating are likely the major source for potential predictability. While there have been recent improvements, both weather and climate models continue to show pervasive deficiencies in representing the magnitudes, structures, and propagation of organized tropical convection. The canonical (but by no means only) problem is that of predicting the evolution the MJO.

Issue 2: Tropical-extratropical interactions

Rossby wave propagation is a dominant feature that influences potential predictability of weather and climate. So getting that right is fundamental. But how do slowly varying forced Rossby wave trains affect weather variability, as manifested by changes in storm behavior and rainfall? Shapiro et al. (2001) demonstrate how the life cycle of synoptic eddies display radically different behavior between the El Niño winter of 1997-98 and the subsequent La Niña winter of 1998-99. These differences result in striking differences in rainfall amounts and patterns, altering regions that are at greatest risk from high impact events as well as the type of storm event (i.e., "warm" high snow level storms vs. "cold" low snow level storms). The changes in the storm system structures between the two years imply large changes in synoptic-scale eddy momentum and heat transports, which can feedback onto the more slowly varying large-scale flow patterns. Bao et al. (2006) show that California flooding events are directly associated with narrow, concentrated plumes of water vapor transported from the tropics to extratropics, with the likelihood of tropical-extratropical interactions depending on whether tropical Pacific ocean conditions were in El Niño, La Niña, or near-neutral states. The importance of these very narrow tropical plumes has significant implications for climate models. It is unlikely that present generation climate models, as are used, for example, in the IPCC assessment, are of sufficiently high horizontal or vertical resolution to properly simulate these narrow plumes, often termed "atmospheric rivers", in which a substantial majority of the poleward moisture transports is apparently accomplished.

Issue 3: Connecting phenomena and processes across time scales

Figure 1 (from the 2006 MJO Workshop, Trieste, Italy) illustrates the complexity of interactions in tropical convection across space and time scales. The failure to model properly processes that

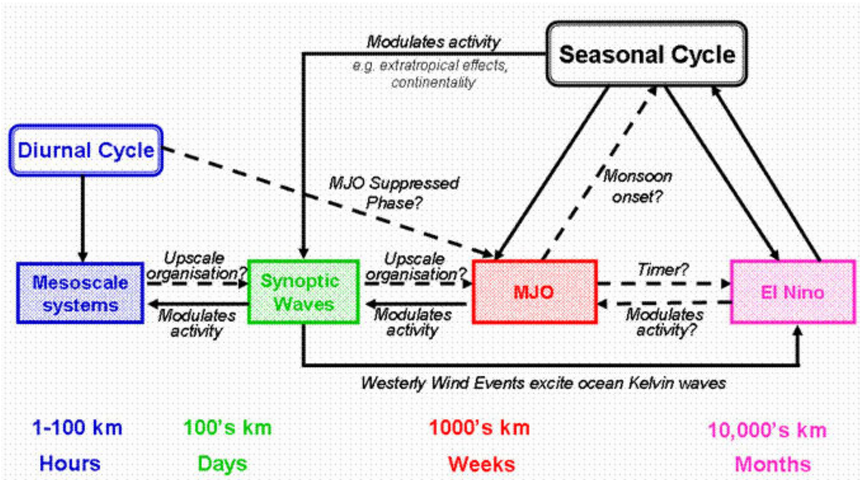

Figure 1 Schematic illustration of interactions between scpace and time scales of tropical convection: Linking THORPEX and WCRP (Courtesy of J. Slingo, 2006)

occur on even diurnal to sub-diurnal processes can alter the time-mean convective heating, which has direct implications for simulating climate. Ocean-atmosphere interactions present a rich interplay between relatively fast and slow processes, and appear to be an important bridge across time scales. For example, relatively fast westerly wind bursts associated with synoptic to intraseasonal time scales can trigger ocean Kelvin waves that influence the evolution of ENSO events, including onset and decay.

Issue 4: Assessing Potential Predictability

Evidence is growing for potential predictability beyond the first forecast week. For example, 8-14 day forecasts prior to the La Conchita Floods/Debris flow disaster (Fig. 2 left panel) showed above normal (upper tercile) rainfall probabilities of around 70% for the region that was subsequently affected, with good indications of a strong connection between the tropics and mid-latitudes consistent with flooding scenarios. By 6-10 days in advance (Fig.2 right panel), the probability of upper tercile rainfall values reached 80-90%. Such high probabilities in the upper tercile were strongly suggestive of a potential for exceptional rainfall, as has been confirmed in other work carried out by Hamill and Whitaker looking at shifts the forecast probability distribution functions for precipitation during this period.

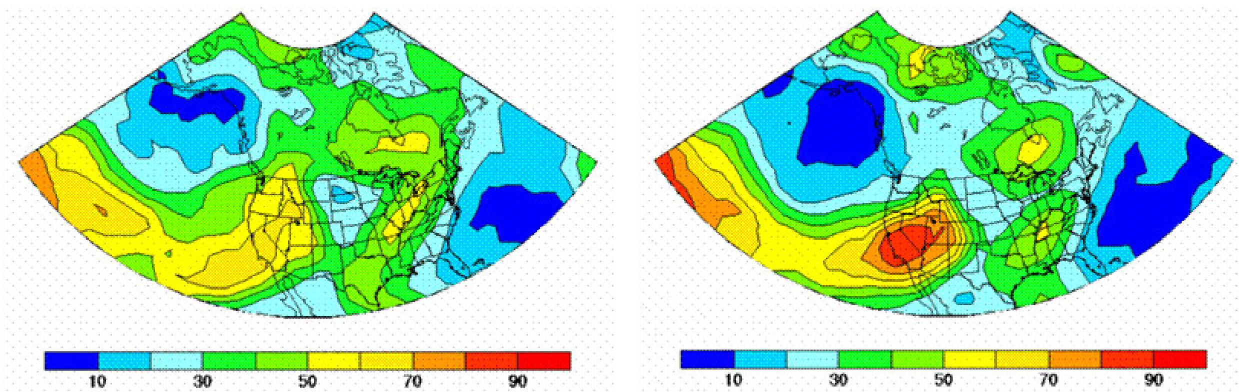

Figure 2 Left panel: week-2 (8-14 day) forecast of the probability (in percent) of above-average precipitation for a forecast initialized at 0000 GMT on 2 January 2005, using calibrated probabilities based on reforecasts. (The La Conchita, CA landslide occurred on 12 January 2005, following massive rainfall along the California coast). Right panel: 6-10 day forecast of the probability of above-average precipitation for a forecast initialized at 0000 GMT on 3 January 2005.

Toward Bridging Weather and Climate

We are beginning to see real evidence for the convergence of weather and climate research. For weather research, The Observations, Research, and Prediction Experiment (THORPEX) under World Weather Research Program (WWRP) is focusing on improving the accuracy of forecasts of high impact weather conditions out to two weeks in advance. There are initial plans for a THORPEX Pacific-Asian Regional Campaign (TPARC) (2008-2009) that will focus significant efforts on improving understanding of tropical-extratropical interactions. Within climate programs, the Coordinated Observation and Prediction of the Earth System (COPES) under the World Climate Research Program (WCRP) proposes to address the seamless prediction problem from weeks to centuries in advance. Thus, there are the beginnings of a bridge between major weather and climate programs on time scales of a few weeks. A "Year of Coordinated Observing, Modeling and Forecasting" is being discussed that would help link weather and climate programs to focus on improving understanding of organized tropical convection and its impacts on the extratropics.

Beyond these programs, the U.S. Climate Change Science Program (CCSP) Strategic Plan identifies as one of its high priority questions how extreme events, such as droughts, floods, wildfires, heat waves and hurricanes are related to climate variability and change. It is also noteworthy that over the past several years, major modeling centers in the U.S. and abroad are beginning to move from separate "weather" and "climate" models toward more unified weather-climate model architectures.

Science Challenges

Some of the key near-term science challenges are:
1. Modeling and prediction of organized tropical convection (MJO, ISO …)
2. Tropical-extratropical interactions; storm tracks and moisture transports.
3. Role of atmosphere-ocean interactions in intraseasonal variability.
4. Systematic zonal flow variations: mechanisms and predictive implications.
5. Predictability of tropospheric wave guides and baroclinic wave packets.
6. Troposphere-stratosphere interactions; modeling and potential predictability.
7. Variability of climate modes beyond ENSO and MJO.
8. Effects of global ocean conditions, e.g., tropical Indian and Atlantic Oceans.
9. Effects of land surface processes.
10. Warm season climate system and its predictability.
11. Potential implications of climate change.

Other Challenges

Traditionally, different scientific communities have focused on "weather prediction" and "climate prediction". We need to move past this dichotomy and build stronger links between the two communities. From a programmatic point of view, research programs have tended to be "stove piped" along disciplines. This has resulted in putting priority on activities in the heart of the disciplines, leaving cross-cuts - such as weather-climate linkages - as "orphans". These barriers must be overcome, and increased emphasis placed on activities that bridge weather and climate research goals. There is a need to develop more scientists who are "fluent" in both weather and climate problems, and in the associated methodological approaches.

Summary

Progress in our understanding and capabilities to predict phenomena at the interface between weather and climate has been impressive. Research also illuminates areas where substantial further advances are possible. Emerging thrusts in international and national research programs suggest that over time artificial distinctions will be removed between "weather" and "climate" as we begin to achieve a more unified understanding of phenomena and processes across time scales. Over the next decade, it is likely that improving understanding and capabilities to predict the links between weather and climate will serve as increasingly vital components of an overall research strategy in Earth system science.

Reference

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